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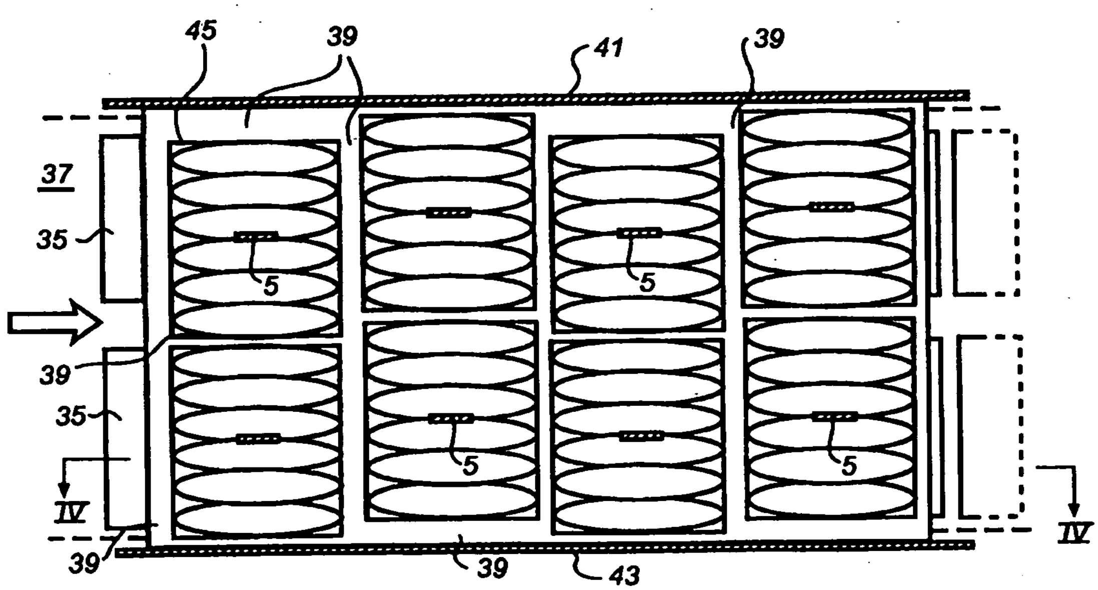
(54) Title: MICROWAVE HEATING APPARATUS




(57) Abstract

A microwave heating apparatus and a microwave heating system comprising a plurality of such apparatuses in a staggered configuration. Each apparatus comprises a so-called open-ended microwave waveguide applicator dimensioned and fed so as to support a dominating resonant quarterwave mode for a load having low effective relative permittivity.

# MICROWAVE HEATING APPARATUS

## Title of invention

Microwave heating apparatus and system using same.

## Technical field

The present invention relates to the field of microwave heating, in particular to a microwave heating apparatus and a system using such apparatuses. The invention is particularly suitable for heating flat loads heated while passing a microwave apparatus and carried on a suitable conveyor.

## Background of the invention

One prior art microwave heating apparatus typically operates at a predetermined frequency and comprises an open-ended microwave waveguide applicator which preferably has a rectangular cross-section and a longitudinal dimension from a closed end to second open end. A metal plate is positioned opposite said open end parallel thereto and spaced therefrom such that a load can be inserted into the space between said open end of the applicator and said metal plate. The load is typically carried by a microwave transparent conveyor passing through said space close to said plate. Means are provided for feeding microwaves of said predetermined frequency into the applicator such that said microwaves propagate from said closed end towards said open end for being absorbed by the load so as to heat the same.

A microwave heating apparatus of the above-mentioned kind is disclosed in the European patent application No. 96108790.5. That application addresses the problems of even heating of the load, high efficiency and low leakage

of microwave energy away from the apparatus. The application teaches a solution to these problems by using a particular combination of hybrid modes of a specific nature, undesired modes being prevented by making them non-resonant. The excitation of a desirable combination of specific hybrid modes while suppressing undesired modes means rather complicated dimensioning and feeding considerations.

## Object of the invention

Although the above-mentioned solution means an improvement, there is still a need for further improvements with regard to the problems discussed.

Thus, the object of this invention is to provide a further improved microwave heating apparatus while at the same time giving simplified considerations with regard to dimensioning of the applicator and the feeding of microwaves into it.

## Summary of the invention

The above-mentioned object is achieved by means of a microwave heating apparatus, a microwave heating system incorporating such apparatuses and a use of such apparatuses having the features defined in the appended claims.

Thus, the invention is based upon an insight that the mode to be used in the applicator should be a resonant quarterwave mode when the relative effective permittivity (here called $\varepsilon$) of the load is low, typically below about 40, that is, the wave impedance of the mode being higher within the load than in the applicator space.

Consequently, according to a first aspect of the invention, there is provided a microwave heating apparatus having a waveguide applicator dimensioned so as to sup-

port a resonant quarterwave mode when heating a load having a low ε.

According to the invention, it is advantageous that the applicator is dimensioned so as to support a so-called Brewster mode when said ε of the load is high, that is, typically above about 40. This means that there will be an automatic gradual change of mode, although with the same horizontal indices, when during a heating process the ε of the load changes from being high to being low, or vice versa. A typical example in this respect is a drying process where the load initially is quite wet, thus having a very high ε, and ends up being quite dry, thus having a very low ε. This means a substantial improvement of efficiency and flexibility, because the energy coupling and the matching of the microwave generator remain essentially unchanged during the entire process.

Also, it has surprisingly been found that the use of a resonant quarterwave mode means that the heating effect will be substantially less sensitive to the height or thickness of the load than in prior art system, thereby also improving efficiency and flexibility of the microwave heating process.

Furthermore, it turns out that the microwave leakage out from the microwave heating apparatus will be very low despite the resonance of the quarterwave mode, because the field components of said mode at the open end of the applicator will be such that no substantial Poynting vector out from the applicator will be created. Also, the induced currents in the applicator walls at the open end will be controlled in a favourable way.

According to the invention, it is preferred that the applicator is dimensioned and fed so as to support substantially only one dominating mode. It has surprisingly

been found that this can be achieved quite easily by having an excitation such as to eliminate unwanted modes, namely by having a suitable coupling slot positioned in the centre of the closed end of the applicator, the slot having an extension parallel to one of the side walls of the applicator, preferably parallel to a smaller dimension of a rectangular cross-section of the applicator.

In order to obtain good quarterwave resonance conditions, a long mode vawelength is preferred. Thus, according to a preferred feature of the invention the effective longitudinal dimension of the applicator (that is, in practice the distance between the closed end of the applicator and the load) corresponds to one quarter of the mode wavelength. However, it should be realised that said longitudinal dimension could be increased by a number of full half wavelengths.

It has been found that it is preferable to have the applicator dimensioned to support a dominating heating mode of the type $TM_{mn}$. Preferably, m should be even and n should be odd. In particular, n should be low, advantageously 1. It has been found that a particularly advantageous mode type is $TM_{61}$.

Given a rectangular cross-section of the applicator and the above-mentioned mode type, it has been found advantageous to have a coupling slot of the kind mentioned above extending parallel to the smaller dimension of the cross-section as well as parallel to the direction of the load moving past the open end of the applicator, because any leaking field will then be weaker in that direction than in the direction perpendicular thereto. The leaking field in the latter direction can be taken care of by means of additional confining or tunnel side walls.

According to a second aspect of the invention, there is provided a microwave heating system comprising a plurality of microwave heating apparatuses of the kind dis-

cussed, said apparatuses being arranged in at least one row in a staggered configuration such that a load passing said apparatuses while being heated will be subjected to a very even heating. Advantageously, the apparatuses of the row are mutually staggered a distance which is about a quarter of the free space wavelength of the applicator mode, whereby in the line of the row a cold spot of the heating pattern of an apparatus of the row will be followed by a hot spot of the heating pattern of the following apparatus of the row. Thus, the load passing the apparatuses will be evenly heated. It will be realised that the staggered distance can be the transverse offset between two adjacent apparatuses of the row.

A third aspect of the invention means a use of a dominating resonant quarterwave mode in a so-called open-ended microwave waveguide applicator for heating a load at the open end of said applicator.

Finally, a fourth aspect of the invention means a use of a dominating resonant quarterwave mode/Brewster mode in a so-called open-ended microwave waveguide applicator for heating a load at the open end of said applicator, the dominating mode being a resonant quarterwave mode when the relative effective permittivity ε of the load is low and a Brewster mode when said relative effective permittivity ε of the load is high.

The invention will be better understood when reading the following description of non-limiting embodiments while referring to the enclosed drawings.

## Brief description of the drawings

Figure 1 is a schematic plan view of an embodiment of a microwave heating apparatus according to the invention.

Figure 2 is a schematic cross-sectional view of the apparatus of Figure 1, taken along line II-II in Figure 1.

Figure 3 is a schematic plan view of an embodiment of a microwave heating system comprising several microwave heating apparatuses of the kind disclosed in Figures 1 and 2, some of the microwave feeding means being removed for the sake of clarity.

Figure 4 is a schematic cross-sectional view of the system of Figure 3, taken along line IV-IV in Figure 3.

Description of embodiments

Figures 1 and 2 schematically show an embodiment of an industrial microwave heating apparatus in accordance with the invention. The apparatus shown comprises a metal waveguide applicator 1 having a rectangular horizontal cross-section and a vertical propagation direction of the microwaves excited in the applicator. The upper horizontal end 3 of the applicator is closed. A rectangular coupling slot 5 is provided in the centre of said closed end 3 of the applicator, the slot 5 extending parallell to the longer dimension of the rectangular cross-section of the applicator. The coupling slot is fed by a conventional rectangular $TE_{10}$ waveguide 7 extending vertically and at its upper end connected to a microwave source 8, waveguide 7 being fed with an antenna 9. Source 8 is mounted on the waveguide 7. For adapting to the coupling slot 5, the end of waveguide 7 connecting to slot 5 has a decreasing internal height (so-called b-dimension) so as to finally being the same as the width of the slot. The above-mentioned microwave feeding arrangement is of a generally conventional nature and, therefor, is not described in more detail.

The opposite end 11 of applicator 1 is horizontal and open while co-acting with a metal plane or plate 13

parallel to and spaced from said end 11 such that a tunnel-like load space 15 is provided therebetween. The smaller side walls 16, 17 of applicator 1 are extended downwards and connected to said plate 13, thereby confining said load space on two opposite sides, that is, the sides corresponding to the smaller dimension of the applicator cross-section. As will be realized, there will be two opposite slot-like bottom openings on the two other sides of the combination of applicator 1 and metal plate 13, these openings giving access to the load space 15.

Also, the respective lower edges of applicator side walls 19, 20 of said two other sides are each provided with outwardly projecting metal flanges 21 and 22, respectively, that is, parallel to the metal plate 13. Such flanges help reducing microwave leakage to the outside.

A microwave transparent load conveyor 23, suitably a belt conveyor, passes through the tunnel-like space 15 while carrying loads 25 therethrough for being heated by microwaves propagating from coupling slot 5 through applicator 1 to said loads. Typically, said loads 25 can be wet objects, the microwaves heating the objects for drying purposes.

As evident from Figure 1, the direction of movement of the loads through space 15, as indicated by arrows 27, is parallell to the longitudinal direction of coupling slot 5, and thus parallel to the smaller dimension of the applicator cross-section.

Applicator 1 is dimensioned and fed by means of coupling slot 5 in the closed end of the applicator so as to support only one dominating mode which is a resonant quarterwave mode when the relative effective permittivity $\varepsilon$ of the load in space 15 is low and which is a Brewster-mode when said $\varepsilon$ is high, there being an automatic change

of mode dependent on the actual ε of the load. Preferably, the mode is of a general TM type in the load.

The effective vertical length or heigth of applicator is the distance between its closed end 3 and the load 25 and is preferably one quarter of the applicator mode wavelength. This means that there will be a long vertical wavelength resulting in low sensitivity to variations of the load height. Also, those field components which could produce leaking microwaves will be comparitively small over the entire height of the load space, that is, the tunnel opening.

Due to the quarterwave resonance and a general TM type mode, the standing wave of the vertically directed E field will be minimum at the load. Also, the standing wave of the horizontal H field components will be minimum at the load, whereby there will be no substantial Poynting vector causing leakage of microwave to the outside. On the contrary the field components creating the heating of the load will be substantial.

With regard to the horisontal H fields, it has been found that their field "loops" advantageously should have a marked "ellipticity" (cf. Figure 3 to be described below), so as to give a stronger excitation of the desired mode. Thus, elongated H field ellipses are preferred, the direction of the elongation preferably being parallell to the extension of the coupling slot. Also, said direction should be parallel to the direction of the movement of the load through the tunnel-like space. As a result, at the open end of the applicator any field component which could cause a leakage out of the tunnel-like space will be the weaker component, while the associated stronger component will "leak" towards the confining side wall extensions, this causing no problems.

Given a microwave frequency of 2,46 GHz, the following data of the preferred microwave heating apparatus can be given:

Mode type: $TM_{61}$
Effective height: about 180-200 mm
First cross-section dimension: about 375-380 mm
Second cross-section dimension: about 300 mm
Coupling slot width: about 72 mm
Coupling slot length: about 18 mm

A preferred embodiment is that the feeding waveguide 7 has a wide dimension (a) which is the same as the length of the slot 5. This results in a reduction of the strong currents in the waveguide iris which is otherwise created. A reduction of current concentrations is advantageous in view of the quite low wave impedance of the quarterwave resonant mode.

According to the invention, it is preferred to arrange a plurality of microwave heating apparatuses of the kind described, so as to give a microwave heating system that can take care of several loads at a time and can provide effective and even heating also when the $\varepsilon$ of the load varies during the heating process. Such a system is schematically shown in Figures 3 och 4, the microwave generating and feeding means being omitted but for the coupling slot 5, for clarity reasons.

The system of Figures 3 och 4 comprises eight apparatuses of the kind shown in Figures 1 and 2. Thus, eight applicators 31 are arranged in two parallel rows above a common metal plate 33, each row thus having four applicators. Adjacent applicators of each row are staggered relative to each other, so that the coupling slots of such adjacent applicators are transversly displaced or offset relative each other a certain distance. In other words,

the coupling slots of the applicators of one row are transversly alternatingly displaced half said distance relative to a row centre line. Each row of applicators heat an associated row of loads 35 carried by a common conveyor belt.

The applicators 31 all have circumferentially outwardly projecting flanges 39 (corresponding to flanges 21 and 22 in Figure 1) at their open end, the flanges of adjacent applicators being interconnected so as to provide a totally confined structure seen from above. At the two longitudinal sides of the system, the respective flanges 39 are connected to vertical metal side elements 41, 43 which are connected to metal plate 33, thereby providing a completely confined tunnel-like configuration.

In Figure 3, there is indicated typically horizontal H field loops 45 in the closed end of the applicator for the preferred mode type, namely $TM_{61}$. As can be seen, a staggering of the applicators of a row by a distance such that the transverse offset between two adjacent applicator slots 5 of a row will be about half the small dimension of the "ellipses", an overall even heating pattern will be obtained. Given a microwave frequency of 2,46 GH2, an offset of about 63 mm has been found advantageous. This corresponds to an offset of about a quarter of the free space wavelength.

As shown in Figure 3, laterally adjacent applicators of the two parallel rows of applicators are spaced a suitable distance which in combination with the abovementioned staggering of the applicators of a row will give an overall even heating pattern, that is, over the entire width of the heating system.

Using a microwave heating system in accordance with the invention means that the microwave energy of each applicator will be well confined by each applicator and the co-acting metal plate so that surprisingly there will be very little coupling (so-called crosstalk) between adjacent applicators in addition to a low leakage to the outside at the two slot-like openings of the tunnel-like load space. The very low coupling between adjacent applicators eliminates the risk of loosing control of the heating pattern as well as loss of power due to interaction of the multiple microwave generators used (that is, one generator for each applicator).

In particular, having elongated H field loops directed as discussed and shown in Figure 3 means that currents induced in the applicator walls at the open end of the applicator will be directed such that there will be very little leakage field in the direction of transportation of the load through the load space, as well as out of the load space at its openings. This is of primary importance. Currents giving field effects transversly are of less importance due to the lateral confinement and the fact that some interaction between parallel applicator rows heating separate loads generally also is of less importance.

It should be noted that when using a quarterwave resonant mode/Brewster mode having a successive or automatic change therebetween dependent on the $\varepsilon$ of the load, there will be no leakage problems when the Brewster mode prevails in view of the very low reflection of microwaves at the load.

Also, it will be realized that an automatic mode alteration can be very advantageous when heating a load in a system having many applicators in series, because the

modes and the heating effects of the applicators automatically and successively will adjust to a changing ε of the load, for instance due to a drying effect thereon.

The invention is not limited to the embodiments disclosed and discussed but various modifications and variations are possible within the scope of the dependent claims. For example, the orientation of the applicators need not be vertical but can be changed due to specific operating conditions. Also, various configurations of mutually staggered microwave heating, apparatuses are possible in view of demands on length and width of the microwave heating system.

Also, deviations from the rectangular cross section are possible, since the theory for the modes is not dependent on the shape of the applicator cross section. Furthermore, the cross section may also be allowed to vary somewhat, in order to accommodate needs for higher impedance in the ceiling (feeding) region, which is accomplished by larger dimensions there - or needs to achieve a stronger quarterwave resonance effect (with all its advantages) for load with reather high ε, which is accomplished by making the applicator slightly smaller near its open end. - When circular cross sections are used, it is advantageous to select only higher order modes which have a substantial H field in the centre region. The preferred modes are then of the type $TM_{1n}$, where n is an integer.

Another embodiment which is space-saving is the use of regular hexagonal applicators in a honeycomb pattern. The modes in such cross section applicators can be approximated by the modes in circularly cylindrical applicators. Analogous constraints and preferences thus apply.

CLAIMS

1. A microwave heating apparatus operating at a predetermined frequency and comprising an open-ended microwave waveguide applicator having a preferably rectangular cross-section and a longitudinal dimension from a first closed end to a second open end, the apparatus further comprising a metal plate positioned opposite said open end parallel thereto and spaced therefrom such that a load can be inserted into a space between said open end of the applicator and said plate, means for feeding microwaves of said predetermined frequency into said applicator such that they propagate through said applicator from said closed end towards said open end, the applicator being dimensioned so as to support a resonant quarterwave mode therein when the relative effective permittivity ε of an inserted load is low, typically below about 40.

2. A microwave heating apparatus as claimed in claim 1, wherein the applicator is dimensioned so as to support a Brewster mode when said permittivity ε of an inserted load is high, typically above about 40.

3. A microwave heating apparatus as claimed in claim 1 or 2, wherein the applicator is dimensioned and fed so as to support substantially only one dominating mode.

4. A microwave heating apparatus as claimed in anyone of the preceding claims, wherein the effective longitudinal dimension of the applicator corresponds to one quarter of the mode wavelength.

5. A microwave applicator as claimed in anyone of the preceding claims, wherein the applictor is dimensioned to support a dominating mode of type $TM_{mn}$, where m is even and n is odd, n preferably being 1.

6. A microwave heating heating apparatus as claimed in claim 4, wherein the applicator is dimensioned to support a dominating mode of type $TM_{61}$.

7. A microwave heating apparatus as claimed in claim 6, wherein said microwave feeding means provide a microwave frequency of 2,46 GHz, said applicator cross-section having a first dimension of about 375-380 mm and a second dimension of about 300 mm, the effective height of the applicator being about 180 - 200 mm.

8. A microwave heating apparatus as claimed in anyone of the preceding claims, wherein said means for feeding microwaves comprise a coupling slot provided in the centre of said closed end of the applicator and parallel to a side wall of the applicator.

9. A microwave heating apparatus as claimed in claim 8, wherein said coupling slot extends parallel to the smaller dimension of the rectangular cross-section of the applicator.

10. A microwave heating apparatus as claimed in claims 7 and 9, wherein said slot has a length of about 72 mm and a width of about 18 mm.

11. A microwave heating system comprising a plurality of microwave heating apparatuses as claimed in anyone of claims 1-10, wherein said apparatuses are arranged in at least one row in a staggered configuration.

12. A microwave heating system as claimed in claim 11, where adjacent microwave heating apparatuses of the row are mutually staggered a distance which is about a quarter of the free space wavelength.

13. A microwave heating system as claimed in claim 11 or 12, wherein each microwave waveguide applicator has outwardly transversely projecting metal flanges at its open end, the metal flanges of adjacent microwave waveguide applicators being interconnected.

14. Use of a dominating resonant quarterwave mode in a so-called open-ended microwave waveguide applicator for heating a load at the open end of said applicator.

15. Use of a dominating resonant quarterwave mode/Brewster mode in a so called open-ended microwave waveguide applicator for heating a load at the open end of said applicator, the dominating mode being a resonant quarterwave mode when the relative effective permittivity $\varepsilon$ of the load is low and a Brewster mode when said relative effective permittivity $\varepsilon$ of the load is high.

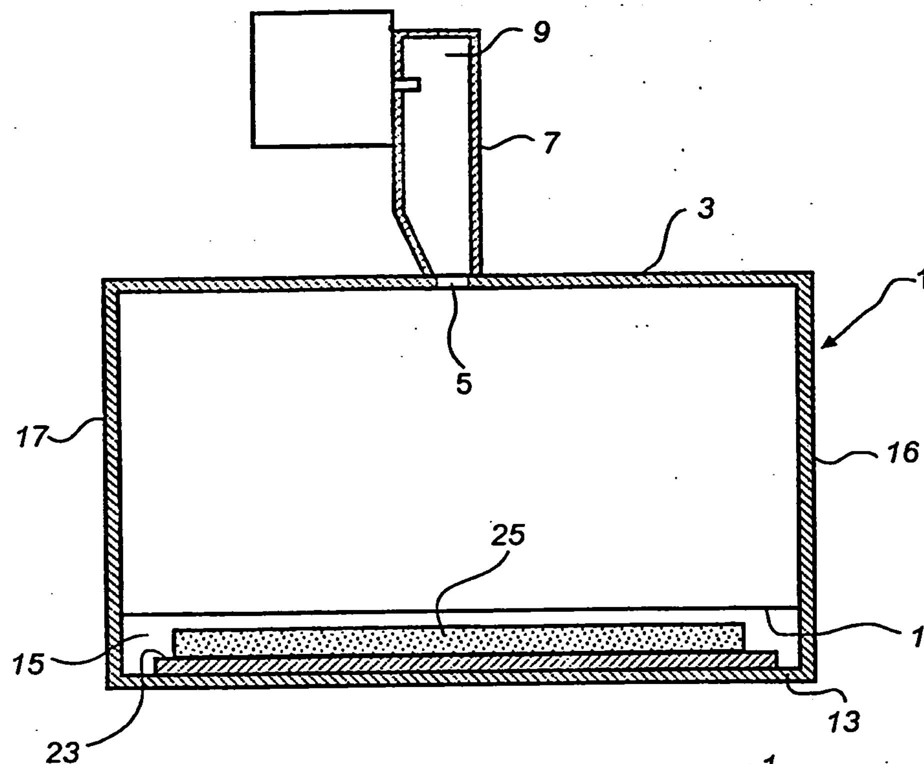



Fig. 2

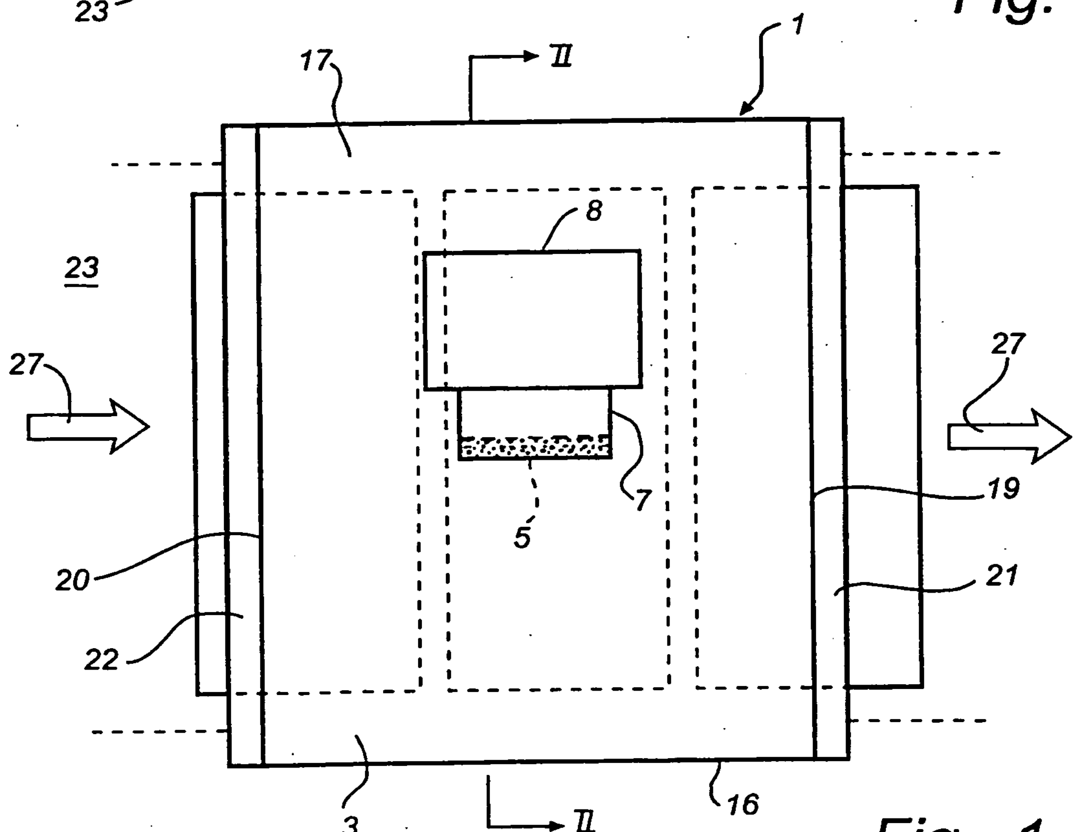



Fig. 1

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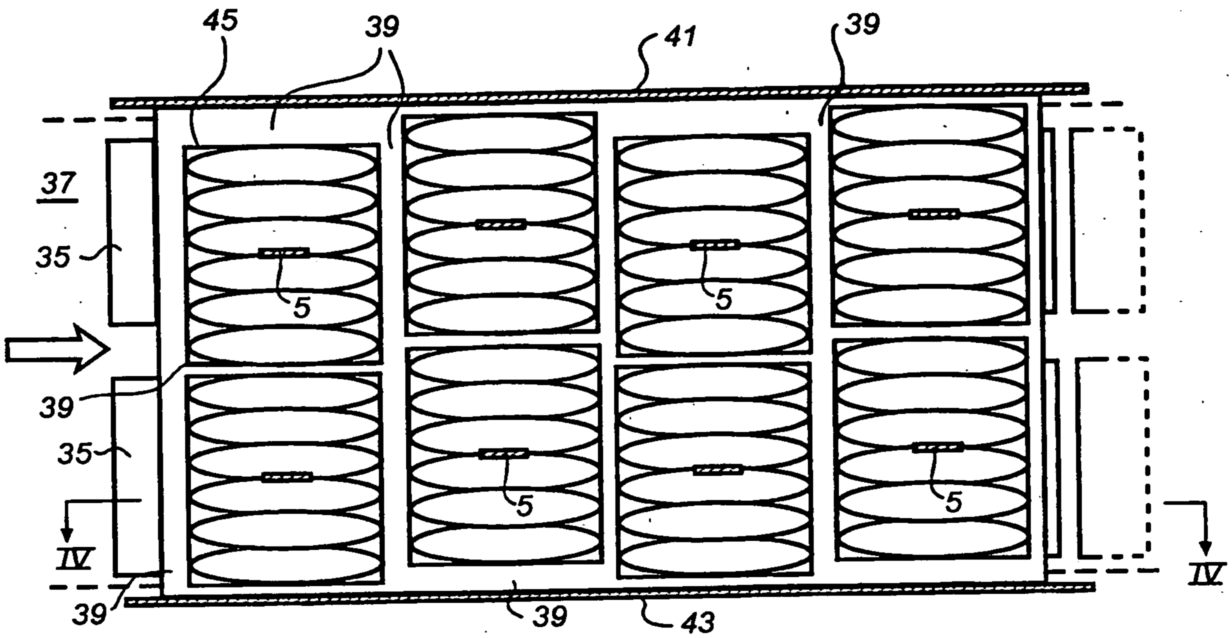
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Fig. 3

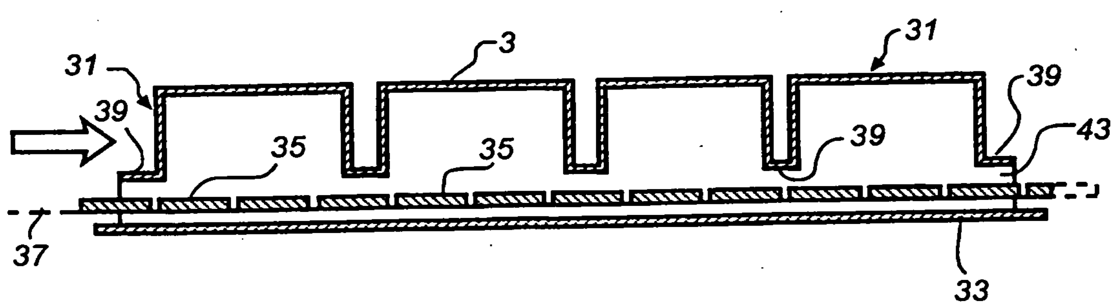
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Fig. 4

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/SE 99/00375

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 6 H05B6/78 H05B6/74

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | EP 0 746 182 A (RUBBRIGHT GROUP INC) 4 December 1996 (1996-12-04) abstract | 1 |
| A | US 3 048 686 A (AMERICAN PHILIPS CO. INC.) 7 August 1962 (1962-08-07) claim 1 | 1 |
| A | FR 2 478 930 A (TECHNICS LAMBDA INTERNAL) 25 September 1981 (1981-09-25) | |
| A | FR 2 275 961 A (ANVAR) 16 January 1976 (1976-01-16) | |

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
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| 8 July 1999 | 15/07/1999 |

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/SE 99/00375

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| EP 0746182 A | 04-12-1996 | US 5828040 A<br>CA 2177905 A | 27-10-1998<br>01-12-1996 |
| US 3048686 A | 07-08-1962 | GB 896422 A | |
| FR 2478930 A | 25-09-1981 | NONE | |
| FR 2275961 A | 16-01-1976 | US 4005301 A | 25-01-1977 |